

Full length article

Animals, metal and isotopes: Mikhailo-Ovsyanka I, the Late Bronze Age mining site of the steppe Volga region

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ABSTRACT

The aim of this paper is to analyze animal bone assemblages from Mikhailo-Ovsyanka I, which is a Srubnaya settlement located in the Middle Volga, and, based on this analysis, get a better understanding of the economic life of the earliest miners, their animal husbandry practices, and the exchange system they developed. Main activities of the local population centered on mining; free range animal husbandry was a secondary occupation. The paleozoological, isotope and seasonality data reflect the subsistence system of the local Srubnaya population. It included seasonal (summer–autumn) search for copper ore and its extraction, small-scale smelting of metal and casting of items; exchange of ore/metal/goods for animals; free range animal husbandry with seasonal grasslands used on a rotational basis. Presence of non-local cattle bones suggests that the metal-animal exchange system began to evolve at small-scale metallurgical centers such as Mikhailo-Ovsyanka I in the Middle Volga region roughly in 1800 calBC. However, mineral resources were not abundant in this area and, most likely, the miners were forced to search other deposits. The situation was different at Gorny, Kargaly, which was a large Srubnaya mining site in the Urals where people lived all year round. They developed a special ore/metal–animals exchange system and extracted ore and exchanged it for cattle throughout three hundred years.

1. Introduction

1.1. Research questions

The subsistence system of the population inhabiting the Middle Volga region in the Bronze Age was based on a sophisticated set of production strategies including mining and metalworking which became especially relevant starting from the second millennium BCE. The beginning of copper smelting from ore and metalworking was an innovation which transformed the cultural and economic landscape of the Volga-Urals region and the life of its population that began to exploit large and small mines of cupriferous sandstone in the Volga-Kama and the Urals regions.

Most likely, the exploitation of small mines in this region began early in the second millennium BCE (Tkachev, 2009, 2012, 2017;

Peterson et al., 2016; Kuznetsov and Mochalov, 2016). A small mining settlement known as Mikhailo-Ovsyanka I was discovered in the Pestravka district of the Samara region in the left-bank Volga basin that is a part of the Obschy Syrt Upland. This mining settlement occupied by the Srubnaya population was located on the left bank of the Ovsyanka river, which is a right tributary of the Bolshoi Irgis river (Fig. 1) far from other Srubnaya sites (Kuznetsov and Mochalov, 2016, Fig. 4, 4) and relatively far from cupriferous sandstones of the Volga-Kama region exploited in the second millennium BCE. The settlement was built on steep ravine slopes which reveal copper oxides, i.e. malachite-azurite inclusions, in the outcrop of calcareous rock. Most likely, this outcrop of copper minerals attracted attention of the Late Bronze Age miners.

The rock foundation of the Obschy Syrt Upland where the site in question is located consists of sedimentary rock of the Permian period. Copper mineralization is associated with the Upper Kazanian fine-

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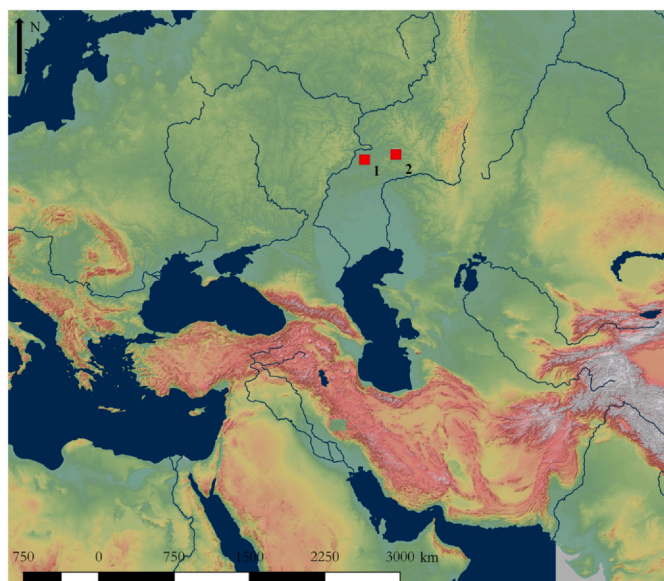


Fig. 1. Location of the sites: 1 – Mikhailo-Ovsyanka I; 2 – Kargaly, Gorny.

grained, heavily eroded limestone and is represented by cuprous carbonates and copper oxides, i.e. malachite, azurite and red copper. Traces of copper mineralization were discovered by the geologist N. Nebritov not only in the Ovsyanka ravine but also near the village of Padovka located at a distance of 6–7 km from Ovsyanka ravine (Nebritov, 2003: 138). The presence of a rather extended mineralogical field in the limestone located at a distance from main copper ore regions is an important geological phenomenon for the studied region. It is well known that in the Kazanian age the highest mineralization is typical for sandstone while the lowest mineralization characterizes limestone (Nebritov, 2003: 136). At the same time the highest concentration of copper is typical for copper mineralization of the top bench of the Lower Kazanian substage which is thin. It is the result of the hydrothermal infiltration origin of copper deposits of the West-Urals copper mineralization region (Nebritov, 2003: 135).

Field excavations at Mikhailo-Ovsyanka I were carried out in 1971, 1978–1979, 1999, 2001 (Agapov and Vasiliev, 1976; Matveeva et al., 2004). Interestingly, this is a one-layer site that belongs to the Srubnaya culture. From the very first excavations the archaeologists pointed out that the population of this settlement specialized in metalworking; ore fragments, numerous stone tools used to mine ore and treat ore to prepare it for smelting were found even in dwelling places and supporting structures (Agapov and Vasiliev, 1976: 115–116; 122). The excavations of the early 2000s discovered mines and traces of rock extraction (Matveeva et al., 2004). It became clear that the Mikhailo-Ovsyanka I population searched ore, mined oxide minerals, smelted metal from ore and also cast items.

In many respects, Mikhailo-Ovsyanka I can be compared with the Gorny settlement in the Kargaly copper deposit area in the Orenburg region (Fig. 1). A multi-year comprehensive study of Kargaly, a mining and metalworking center in the Cis-Urals, and the Gorny mining settlement which operated in 1700–1400 calBC (Chernykh et al., 2002b: 125–127; Chernykh, 2007) produced unique data on the emergence and development of this Eurasian metalworking province and a highlighted a special role it played in developing economic and technological potential of the Srubnaya steppe population; it should be noted, though, that this ore deposit began to be exploited by the miners and metalworkers of the Yamnaya culture as early as the third millennium calBC (Chernykh, 2007). In the second millennium BCE metal produced by the large metalworking Kargaly center was supplied not only to the neighboring Srubnaya areas of the Volga-Urals region but also to more distant areas, i.e. the Don, the Donets, the Lower Dnieper regions

(Chernykh, 2007: 17; 67; 71–98. Fig. 3.1).

Both mining settlements are attributed to the Srubnaya culture, they revealed layers made up of mine dumps rich with the artifacts associated with ore mining and metalworking; sacrifice sites with large bones of domesticated animals and pits containing vessels, ore, hammers, ingots, animal bones as well as traces of underground workings (Chernykh et al., 2002a: 66–69). However, quantities of finds at Gorny and Mikhailo-Ovsyanka I are different, suggesting different intensity levels of mining works and the occupation periods at these two settlements.

The thick occupation layer at Gorny located near a large copper deposit in the Urals is abundant with finds, apparently, because of intensive metalworking operations, annual production cycles, and repeated reoccupation of the settlement when even no longer used constructions were turned into dumps to store domestic refuse from other constructions and dwellings. The number of animal bones found at Gorny is around two million, cattle bones account for the highest share (Antipina, 2004). The subsistence strategy at the Srubnaya Gorny settlement changed throughout the period when Kargaly was in operation, which is approximately three hundred years. At the initial stage the miners extracted ore during those seasons of the year which they found suitable for mining as evidenced by seasonal dwellings of a burrow type; permanent dwellings were located somewhere outside Kargaly. Subsequently, the Srubnaya population settled in the Kargaly area, apparently, because the miners worked at the mines all-year-round. However, a relatively small amount of smelter slag, a small number of metalworking tools and a huge amount of bones of domesticated animals suggest that this miners' settlement specialized in extraction and export of copper ore rather than production and export of metal. This specialization model was based on a sophisticated system of goods exchange: ore/metal – product – domesticated animals/meat. The ore was exported to the areas west of and northwest of Kargaly (Chernykh, 2007: 118–120). The archaeozoological analysis of the domesticated animal bones (Antipina, 2004), analysis of wood remains at the settlement (Usquiano, 2002), palynological and other studies at Gorny (Chernykh et al., 2002b) confirm this model.

As for Mikhailo-Ovsyanka I, though constructions, buildings and finds at this site were analyzed (Matveeva et al., 2004), and the tracewear analysis of the stone and bone tools and implements to document mining production at Mikhailo-Ovsyanka I was carried out (Gorashuk and Kolev, 2004), basically, no further studies of the finds were performed. The elemental composition of the ore and the retrieved artifacts were not described in detail and the animal bone assemblage found at the settlement was not analyzed. Under the Samara Valley Project D. Anthony visited this settlement and selected charcoal for ^{14}C dating and samples of cattle and sheep/goat teeth for determining the season of animal slaughter (Anthony et al., 2016a). The date obtained for charcoal, i.e. 1497–1157 calBC (Anthony et al., 2016b. Table 2.1), turned out to be too young. Interesting data were obtained regarding the seasonality of the site. Based on the season when two animals were slaughtered (late autumn/early winter), it was suggested that the mining settlement was seasonally operated (Pike-Tay and Anthony, 2016. Table 14.3).

The number of animal bones found in the occupation layer at Mikhailo-Ovsyanka I is more than 11,000, which is a lot. The analysis of this bone assemblage will provide an opportunity to determine the period when the site was occupied, estimate meat intake of its occupants (Antipina, 2008), check the hypothesis on the seasonal economic cycle used by the miners that was put forward by Pike-Tay and Anthony (2016) and describe the economic activity of the local miners.

The study of the bone assemblage is relevant because, in our view, the 'animal' component of the finds can give an insight into some important aspects of the economic life of its population. Mikhailo-Ovsyanka I is not an ordinary Srubnaya site, its occupants were engaged in mining and their subsistence system was probably different from that developed at other Srubnaya sites in the Volga region.



Fig. 2. Mikhailo-Ovsyanka I: 1–2 – general view; 3–4 – excavation areas.

The aim of this paper is to analyze the animal bone assemblage from Mikhailo-Ovsyanka I, and based on this analysis, get a better understanding of the economic life of the earliest miners, their animal husbandry practices, and the exchange system they developed.

With this in view, our analysis of the Mikhailo-Ovsyanka I archaeozoological assemblage included an isotopic study to identify local/non-local animals based on the isotope composition of the animal bones ($\delta^{15}\text{N}$ and $\delta^{13}\text{C}$) and variation in the strontium isotopes ($^{87}\text{Sr}/^{86}\text{Sr}$) in the animal teeth. Our working hypothesis is based on a premise that 'local' animals owned by the inhabitants of nearby Srubnaya settlements were used and consumed by the people who mined ore, while the presence of 'non-local' animals is an evidence of trade transactions with the population of faraway areas including the population of larger settlements. Further tasks included ^{14}C dating, determination of the seasonality of the site, and the elemental composition of the ore artifacts. The new data are important for gaining knowledge of when Mikhailo-Ovsyanka I was occupied and for how long; clarify whether the production cycle was annual or seasonal; confirm that some products were cast locally; check if the 'metal-animal' system of relationship at Mikhailo-Ovsyanka I shared some similarities with the reconstructed system of links at Gorny located in Kargaly in the Ural region, which is a large metalworking center, and assess the role of a small Srubnaya community in searching copper ores and producing metal.

1.2. Geography and climate

The Obschy Syrt Upland is a flat or gently rolling plateau with strongly dissected margins and slopes facing rivers with asymmetrical

valleys. Flattened surfaces of various elevations (with absolute elevations of 300–320 m, 180–220 m, 100–150 m) are clearly visible on the watersheds, with residual outcrops rising over some surfaces. The slopes of the flattened steppe like terraces are dissected and resemble mountains. The terrain in the southern part of the Obschy Syrt Upland is complicated with dome-shaped masses that correspond to salt-dome swells as well as hills, ranges and ridges separated by deep *balkas* (small flat-bottom valleys with turfed sides and discontinuous flow) and hollows.

The number of ravines is low because of quick overgrowth of erosional furrows. However, a small flat-bottom valley type of erosion develops continuously, and, there are many young small flat-bottom valleys and river valleys with continuous flow in this region, but the dissection is deep. River valleys, with the exception of the stem stream which is the Samara river, are not wide. The rivers are shallow, though they have water all the year round. Flooding is high but short, which is typical for all steppe rivers.

The Obschy Syrt Upland is mostly located in the steppe belt, encompassing a small 'wedge' of the southern forest-steppe only in the north. The steppes have their own landscape features because of the orographic shadow of the Urals mountains (more precipitation in summer) and a rather high elevation of this area. On the one hand, because of harsh continental climate, severe winters (January temperature is -10 – -15 °C) with blizzards and strong winds, the watershed windswept areas are devoid of trees; on the other hand, redistribution of precipitation along the rough terrain creates favorable conditions for humidity in all topographic lows despite summer heat (July temperature is $+22$ – $+24$ °C, maximum temperature is $+40$ – $+43$ °C), these topographic lows are also well protected against wind. All this is conducive

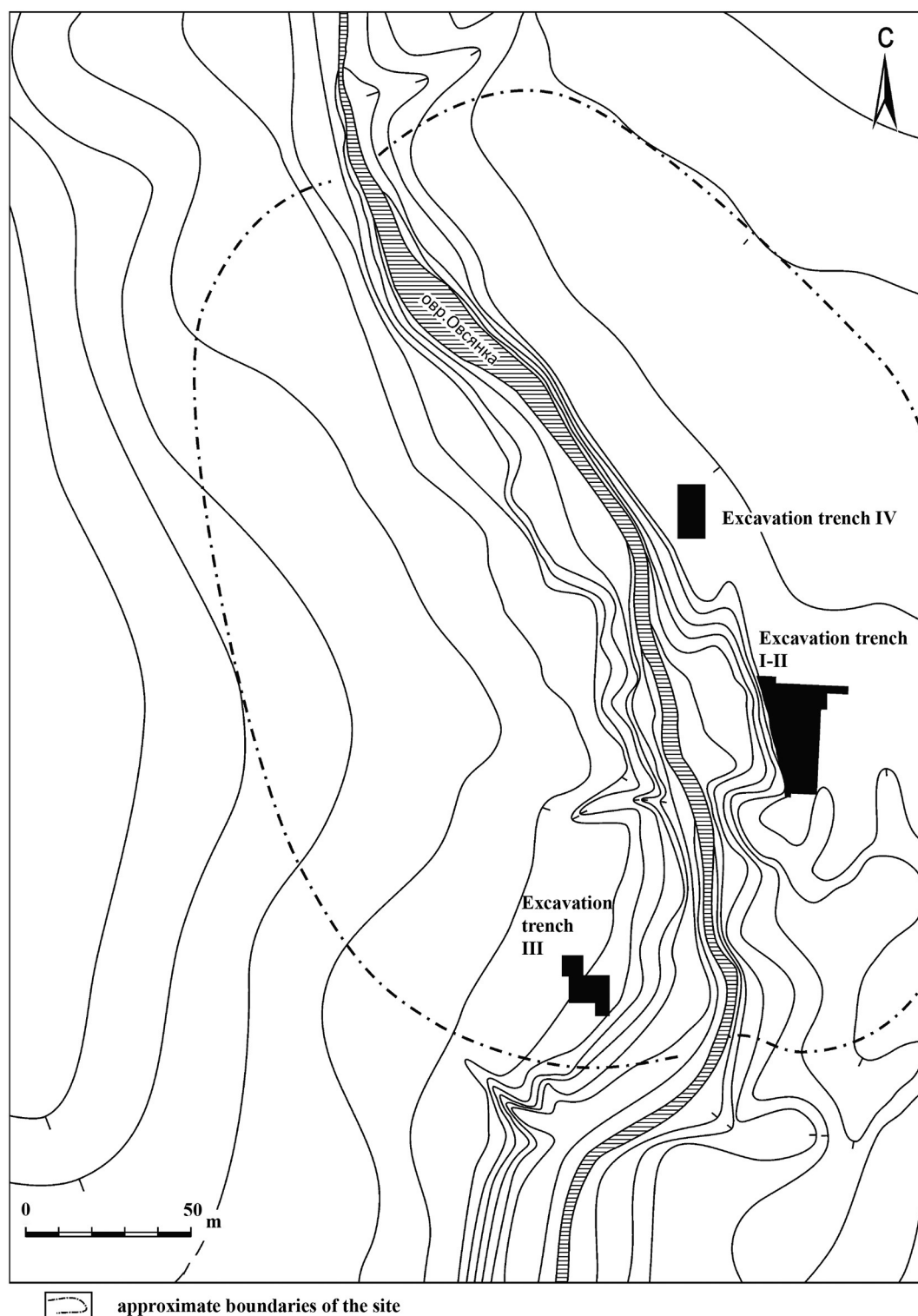


Fig. 3. Mikhailo-Ovsyanka I: plan of the site.

to tree vegetation.

Oak forests with an admixture of linden and birch trees grow in small flat-bottom valleys while birch tree forests grow in the lower parts of the slopes. Feather grass and fescue, feather grass and fob, fescue and fob steppes are common on the watersheds. Soils are represented by typical and southern chernozems.

Winter is the longest season of the year (five months), snow cover may stay until March reaching 50–60 cm (Sidelnikov, 1901: 56).

1.3. Mikhailo-Ovsyanka I: archaeological background

The Mikhailo-Ovsyanka I settlement is located on a gentle slope of a watershed plateau of the Obschy Syrt Upland; a ravine crosses it from the north to the south dividing the site into the right bank and the left bank areas (Fig. 2). Several types of constructions were excavated including prehistoric mining and metalworking constructions, e.g. workings of the mine type; dwellings of miners with a rather thick occupation layer (Fig. 3) abundant with tools, ceramic fragments,

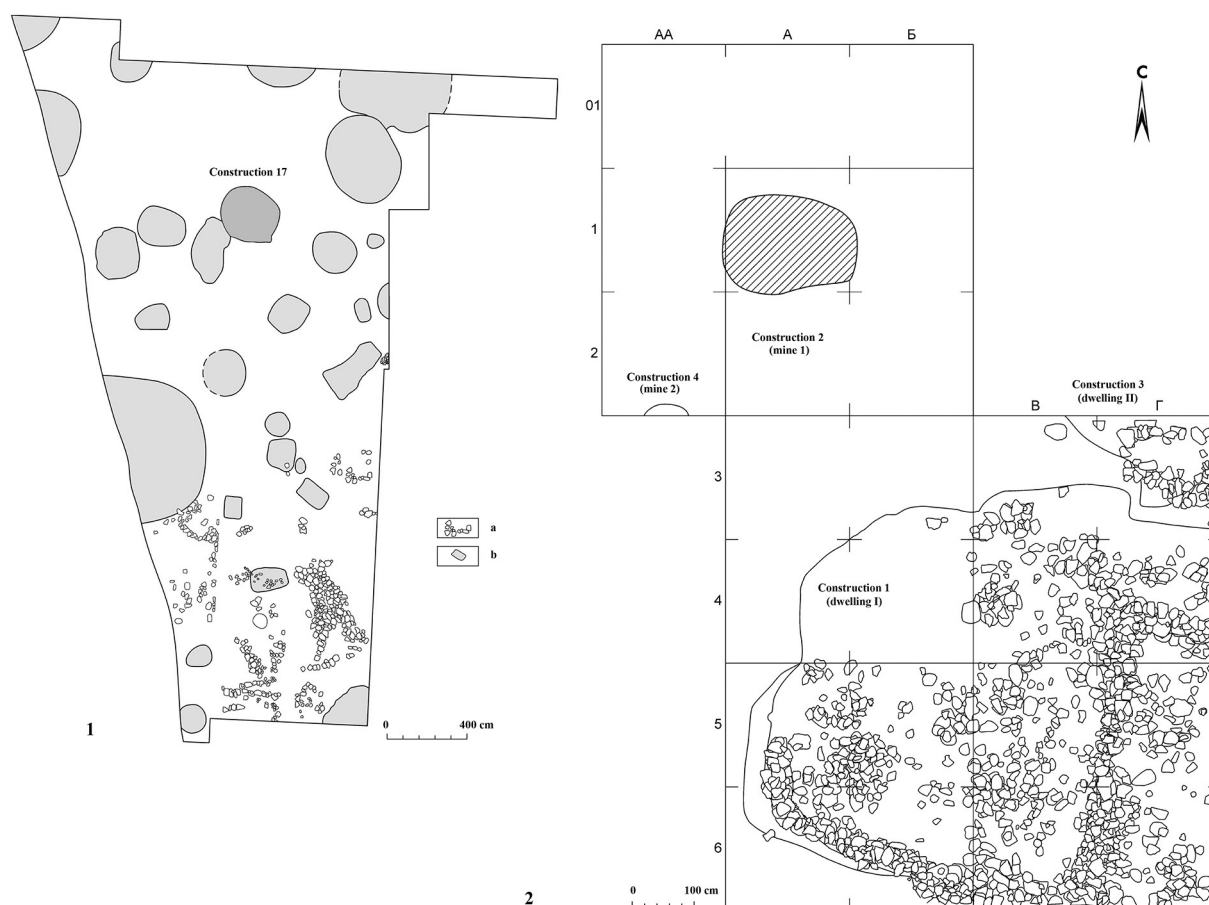


Fig. 4. Mikhailo-Ovsyanka I: 1 – excavation trenches I-II, a – remains of stonework, b – constructions (mines); 2 – excavation trench III (western part) with mines (constructions 2 and 4) and dwellings I and II. Plan.

animal bones and slags (Figs. 4–6).

The scholars identified several stages of this field development in the areas that were potentially productive because the depth of the ore body did not exceed 3–6 m (Matveeva et al., 2004). The technological chain of production operations included the following stages.

The first stage was associated with searching the ore body; mines and adits were discovered both in the right bank and the left bank parts of the site. Presumably, mining operations were conducted in the area ranging from 6 to 7 to 11–12 ha (Fig. 3). Workings of the mine type were round with a diameter of roughly one meter; their depth is from 3 m to 5–6 m. The occupation layer around the mines consists of mine dumps formed during shaft sinking. Most mines (approximately, 18–20) are located on the ravine left bank in excavation trenches I-II, excavation trench IV located north of excavation trenches I-II, and on the ravine right bank in excavation trench III (Fig. 4). The mine in excavation trench III is more than five meters deep. A lot of mines were operated for a short period of time and were abandoned when it became clear that the removed section did not have the copper vein that would make extraction viable.

In case of successful searching of the ore body, the mines were transformed into mining facilities linked to the second production stage which is extraction of metal ore. Adits connecting the mines were made near the bottom of several mines. For example, there is an adit found in the area of excavation trench III (construction 2). The areas where malachite and azurite were cut from metal ore are an evidence of copper ore extraction. Copper traces were also detected on tools made from stone and bone.

Other cycles of mining and metalworking such as beneficiation of ores and smelting took place at the site. Stone and bone tools used to

crush ore, metallurgical slags, fragments of clay crucibles, ingots and copper spatter were found at the site. Construction 26 discovered in excavation trenches I-II was, probably, one of heating plants for metal smelting; stone constructions found in various sections of the settlement could also be classified as heating plants.

Casting was the final stage of the metalworking cycle. Fragments of casting molds, a copper ingot, and some cast artifacts such as a knife, parts of clothing accessories were found at the settlement, they were cast at the site.

It is likely that many mines and adits were quickly filled up with refuse and waste because of a lack of ore or quick extraction of a small amount of ore. Their occupation layer is abundant with animal bones and ceramic fragments.

2. Methods of research and samples

2.1. Archaeozoological analysis

To establish the species composition of the animals consumed for food at Mikhailo-Ovsyanka I, the entire assemblage of more than 11,000 animal bones was examined. Archaeozoological remains at settlements, primarily, reflect meat intake of its occupants. We can also infer from their analysis how meat food was supplied to the population (Antipina, 2008). The taxonomic and anatomic identification of the bones was done at the Research archaeological laboratory in Samara State University of Social Sciences and Education. To distinguish between sheep (*Ovis aries*) and goat bones (*Capra hircus*), we used species specific features identified and published by a number of researchers (Gromova, 1953; Boessneck et al., 1964).

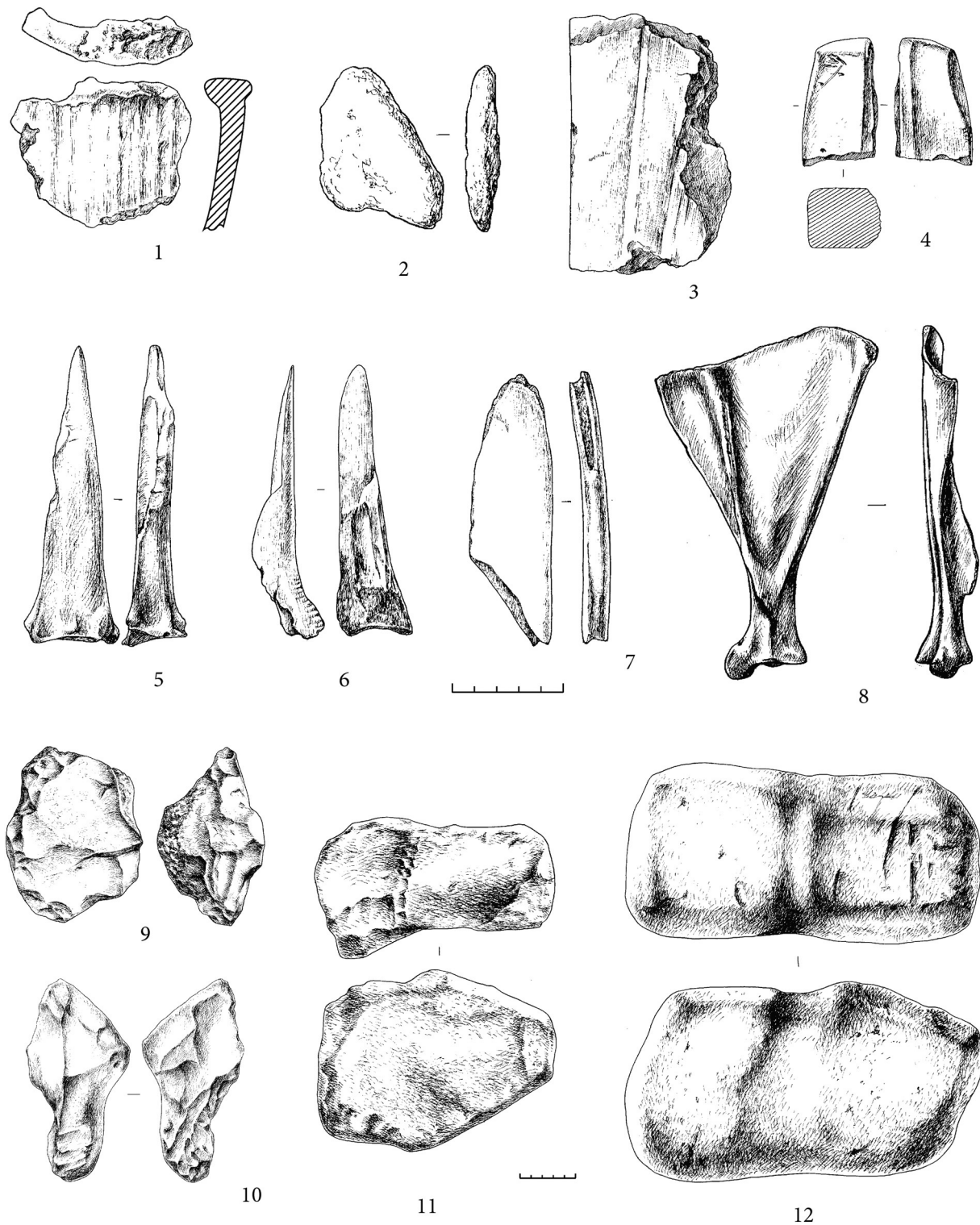


Fig. 5. Mikhailo-Ovsyanka I. Finds related to extraction of metal ore and beneficiation of ores (5–12), metal smelting and metalworking (1–4): 1 – fragment of a crucible (excavation trench III); 2 – copper ingot (excavation trench III); 3–4 – fragments of molds (excavation trench III); 5 – chisel (trench III); 6 – chisel (excavation trench II); 7 – tool for grinding ore (excavation trench IV); 8 – shovel (trench III, building 1, pit 5); 9 – fragment of hammer (excavation trench III); 10 – miner's hack (excavation trench III); 11 – sledge-hammer (excavation trench II); 12 – sledge-hammer (excavation trench III). 1, 3, 4 – clay; 2 – copper; 5–8 – bone; 9–12 – stone

To understand whether the settlement population raised and kept domesticated animals or animals were, probably, brought to the miners' settlement from other places to be exchanged for ore, we analyzed the slaughter age of animals. The data on the slaughter age of domesticated animals also helped understand what system of animal husbandry was used (keeping animals in enclosures at the settlement or free range

animal husbandry) and what role the animals played at the settlement. For example, people could keep domesticated animals for meat, or meat and milk, or wool, and also make use of muscular force of animals. In addition to that, we analyzed the size of unbroken bones and their variability to assess heterogeneity of populations of various animal species.

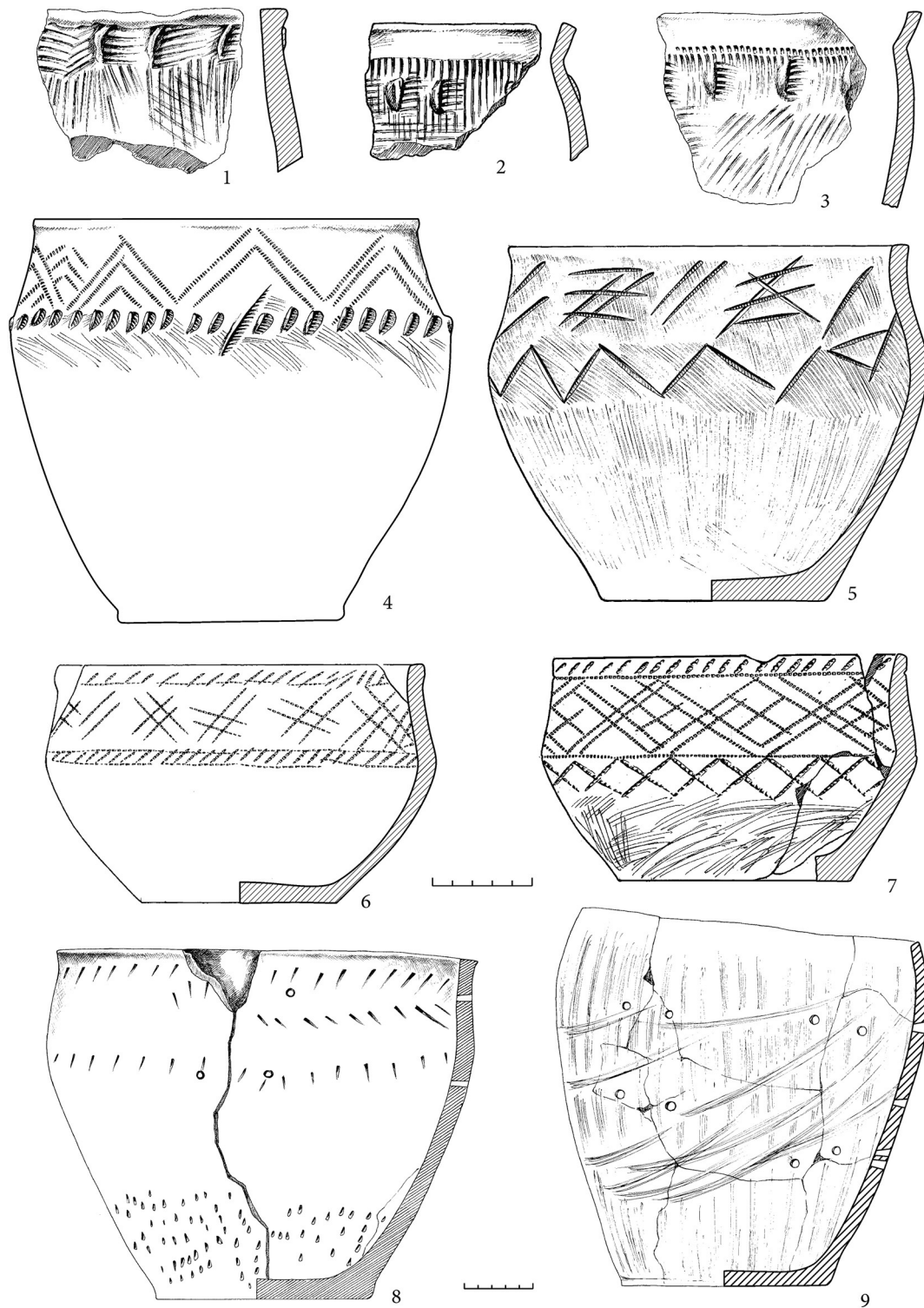


Fig. 6. Mikhailo-Ovsyanka I. Ceramics: 1 – excavation trench I-II; 2–3 – excavation trench IV; 4 – excavation trench IV, construction 1; 5, 9 – excavation trench III, construction 1, pit 1; 6 – excavation trench III, construction 1; 7 – excavation trench IV, construction 6; 8 – excavation trench IV.

The slaughter age was estimated using mandible specimens from predominant species such as cattle and sheep/goats. We used data on exfoliation time (shedding primary teeth and their replacement by permanent teeth) (Silver, 1969).

In addition to that, the age of all adult species which had the last molar tooth (m3) and the age of all individual third molars (m3) from the mandible which appeared worn or began to be used for grinding food was estimated based on tooth surface loss according to the

methodology developed by A. Grant (Grant, 1982). This analysis was done to deduce the slaughter age of adult animals.

We also analyzed the size of the unbroken bones and their variability to assess the heterogeneity of the populations of various animal species. A too wide range of variability in the size of the bones of the same species which exceeds the range of intra-species variability may be indicative of the presence of bones of animals from other sites. The measurements of the cattle, sheep and goat bones were done using A.

von den Driesch's methodology (von den Driesch, 1976). Regarding the first phalanges of the cattle, the greatest length of the peripheral half (GLpe) was measured similarly for the phalanges of the hindlimb and the forelimb (von den Driesch, 1976: 96, Fig. 45d). The size of the sheep and goats was estimated by measuring the first phalanges as the most prevalent group of unbroken bones (129 specimens). The size of the sheep and goats was estimated based on measurements of astragal bones (21 specimens). The range of cattle phalanx variability was estimated by comparing variation coefficients (von den Driesch, 1976). The variability of the cattle first phalanx size was estimated based on the variation factor (Zaitsev, 1991: 9–10).

2.2. Isotope studies

To conduct isotope and seasonality pilot studies, bone samples from the following constructions were selected:

- excavation trench II – construction 17: the mine (only the mine mouth was excavated);
- excavation trench III – construction 1: the foundation pit with a stone structure; its fill-in yielded tools associated with ore extraction and its beneficiation (stone axe picks, hammers, bone implements), smelting traces (a pit with slags, numerous slags, two copper ingots), remains of casting productions (fragments of casting molds, crucibles, copper spatters, smith's hammers);
- excavation trench III – construction 2: a narrow mine with a diameter of around two meters;
- excavation trench IV – construction 4: a mine of irregular shape with a diameter of around three meters.

The isotopic composition of bones from water dependent pasture domesticated animals ($\delta^{13}\text{C}$, $\delta^{15}\text{N}$) is used to reconstruct seasonal husbandry management practices of local pastoralists and possibly identify the scale of husbandry. Significant variations in the values of nitrogen and carbon isotopes are observed within the ecosystems, between the ecosystems and the trophic levels because stable nitrogen and carbon isotope ratios undergo predictable changes (i.e. discrimination) with each trophic step (Iacumin et al., 2000). C_3 and C_4 plants with different carbon isotopes are at the base of the trophic chain. They form the basis of the pasture herbivore forage. The value of $\delta^{13}\text{C}$ of bone collagen from animals demonstrates what C_3 or C_4 type plants are at the base of the trophic chain (Ambrose and DeNiro, 1986). Some climatic factors have an impact on the carbon isotopic composition of the plants. For example, in closed-canopy forests the value of $\delta^{13}\text{C}$ in the sample examined may be lower whereas decreased precipitation may cause increase in $\delta^{13}\text{C}$ (Iacumin et al., 2000).

$\delta^{15}\text{N}$ of plants and animals may be affected by climatic characteristics. Environmental stresses such as aridization cause reduction in annual precipitation, replacement of the vegetation cover, and changes in the water conservation processes. The $\delta^{15}\text{N}$ values of plants and herbivores from the arid areas are higher than the $\delta^{15}\text{N}$ values of the animals from more humid climatic conditions (Schwarcz et al., 1999; Shishlina et al., 2018). A high nitrogen value may be influenced by pasture fertilization (Bogaard et al., 2007). The excavation of the site was carried out many years ago, no flotation was performed. However, E. Lebedeva did some paleobotanical studies and performed flotation at many other Srubnaya settlements (dating to the first half of the second millennium BCE, including Gorny at Kargaly) located in the Volga and the Ural region. No domesticated seeds were found (Lebedeva, 2005). No domesticated seeds were found by the joint Russian German expedition that excavated Kamenny Ambar in the Urals (Ruhl et al., 2014) and by the joint Russian-American excavation at the Srubnaya Krasnosamarskoye settlement located 300 km north of Mikhailo-Ovsyanka I (Popova, 2016). Based on these data, we also assume that there was no agriculture activity at Mikhailo-Ovsyanka; therefore, the agriculture factor may be disregarded.

The isotopic composition of nitrogen and carbon was determined for 15 animal bones. For comparison purposes, we used the isotopic composition data for animal bones of the Bronze Age from the adjacent areas (Shishlina et al., 2018).

The collagen extraction from the animal bones was done at the ^{14}C laboratory of the Institute for the History of Material Culture (IIMK) of the Russian Academy of Sciences. Stable isotope ratio measurements were made at the Vernadsky Institute of Geochemistry and Analytical Chemistry (GEOKHI) of the Russian Academy of Sciences using a DELTA Plus XP isotope mass-spectrometer (ThermoFinnigan) linked to a Flash EA 1112 elemental analyzer. The isotope ratios are reported in permil notation relative to VPDB and AIR for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$, respectively. Each sample was measured in triplicate and the standard deviation of repeated measurements was 0.2‰ and 0.2 to 0.3‰ for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$, respectively. Collagen integrity was assessed by the atomic C/N ratio (DeNiro, 1985).

Variations in the $^{87}\text{Sr}/^{86}\text{Sr}$ values recorded in animal tooth enamel help understand whether animals were local or non-local (Bentley et al., 2004; Gerling, 2015). As a geochemical substitute of calcium, strontium is able to incorporate into the matrix of hydroxyapatite, thereby replacing it and accumulating in dental and bone tissues. Natural strontium consists of four stable isotopes: ^{88}Sr (82.56%), ^{86}Sr (9.86%), ^{87}Sr (7.02%), and ^{84}Sr (0.56%). The abundance of ^{87}Sr varies depending on its formations as a result of the dissociation of natural rubidium (^{87}Rb). The $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in rock or mineral containing Rb depend on the age and the Rb/Sr ratio in the source or parent rock and vary significantly. Sr appears in the trophic food chain from plants which, in turn, absorb it from soil and surface and ground waters. The most significant variations in the $^{87}\text{Sr}/^{86}\text{Sr}$ ratios are observed in the upper 20 cm humic soil layer, where atmospheric precipitations have a considerable impact on the composition and concentrations of chemical elements. However, the variation in the Sr isotope ratio is consistent with that of underlying rocks. The $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of water also depend on the composition and age of eroded rocks. The geological and geochemical characteristics of a particular region determine the composition of Sr, which occurs in plants and other living organisms inhabiting the studied area.

Participating in the trophic chain of plants, soil, ground and surface water of a specific region, strontium gets into animal tissue, animals obtain strontium through water and grazed plants. Variations in the strontium isotope composition are correlated with the geology of the region where such grasslands, most likely, were located.

For comparative purposes, variations in the strontium isotope composition of the enamel and the dentin of local marmot tooth from Mikhailo-Ovsyanka I was used as a baseline. Orographically, the Obschy Syrt (sag and swell) Upland is a continuation of the Bugulma-Belebeys Upland; in contrast to the latter, though, most of its western part is formed by younger Jurassic sand-clay and carbonate sediments deposited onto the bryokram, while its southern part is formed by cretaceous and Paleogenic sediments (chalk, sand, clay, gaize) that superpose the Jurassic sediments. This geological structure demonstrates differences between specific values of the strontium variation for the studied region and those estimated for the baseline samples from the adjacent areas (Shishlina and Larionova, 2013; Shishlina et al., 2016; Trifonov et al., 2012).

Variations in $^{87}\text{Sr}/^{86}\text{Sr}$ ratios were determined for 4 teeth of domesticated animals and 1 tooth of a wild animal.

All measurements were done at the Institute of Geology and Geochemistry in Yekaterinburg according to the published protocol.

2.3. Seasonality

The method of identifying the season of death/slaughter of domesticated animals is based on the analysis of growth layers in bone tissues and teeth of animals. It is suitable for analysis of all mammals of more than one year old which have a seasonality of growth. Seasonal changes in the organism growth lead to formation of growth layers in

Table 1
Osteological spectra of domestic ungulates in the settlement of Mikhailo-Ovsyanka I.

Animal species	Excavation trench II	Excavation trench III	Excavation trench IV	Settlement Total
%				
<i>Bos taurus</i>	72.7	74.7	73.4	73.8
<i>Ovis/Capra</i>	24.8	22.2	25.1	23.6
<i>Equus caballus</i>	2.1	2.1	1.1	1.9
<i>Sus scrofa domestica</i>	0.5	1.0	0.5	0.7
Total	100.0	100.0	100.0	100.0

the teeth and bone tissues. Each annual layer comprises a broad band that is laid down during the period of intensive growth in spring–summer and a narrower band which reflects slowdown of growth in autumn–winter (Klevezal and Kleinenberg, 1967; Grue and Jensen, 1979; Klevezal, 1988). Annual growth layers of ungulates are formed only in teeth (Klevezal, 1988). In teeth the layers are examined in cementum which surrounds the dentine of the root of the tooth (outside tissue) and in dentine (inside tissue). The tooth was first placed in a special resin to prevent destruction of the sample when thin sections and polished sections were cut (Pike-Tay, 1991; Greenfield et al., 2015). Thin sections and polished sections were cut with an IsoMet, which is a low-speed precision sectioning saw. The cut thin sections and polished sections were then examined in reflected or transmitted light with magnification of 7×8 , and, in some cases, with greater magnification. Besides, each thin section or polished section with clearly visible layers was photographed. In some, particularly complicated cases, the photographs clarify the number of layers and the nature of the last marginal layer. The cementum and dentine analysis of the animal teeth was carried out at the Institute of Animal and Plant Ecology, the Urals Branch of the Russian Academy of Sciences, in Yekaterinburg.

To analyze the seasonality of Mikhailo-Ovsyanka I, we selected 6 tooth specimens from various constructions. Published data were used for comparison (Pike-Tay and Anthony, 2016. Table 14.3).

2.4. ^{14}C AMS dating

To determine the period when the site was occupied, we selected 4 animal specimens. AMS-dating was performed at the Poznan ^{14}C laboratory and the Institute of Geography, RAS. Bone collagen was extracted using a modified Longin method (Longin, 1971; Mook and Streurman, 1983). All date calculations were made using the Libby half-life to maintain consistency with other dating records and calibrated using the IntCal13 curve within a Phase model in Oxcal 4.2 (Bronk Ramsey, 2009; Reimer et al., 2013).

2.5. Mass spectrometry (ICP-MS)

The composition of alloys of the ingot, the knife, and the jewelry fragments was determined with the use of the highly sensitive inductively coupled plasma mass-spectrometry (ICP-MS). According to mass spectrometry with inductively coupled plasma atomic emission spectrometry (ICP-AES), the alloy was mostly composed of copper.

A combination of ICP-AES and ICP-MS methods is used to estimate absolute amounts of elements from lithium to uranium (except carbon, nitrogen, oxygen, fluoride, chloride and noble gases) in materials and substances with the determination limit of 10^{-9} wt%.

Measurements were made by a Thermo Scientific iCAP 6300 Inductively Coupled Plasma Optical Emission Spectrometer and (USA) and a PerkinElmer ELAN DRC-E ICP-MSan (USA) at the NRC Kurchatov institute-IREA. Standard ICP-MS-68B-A-100 (High-Purity Standards, USA), ICP-MS-68B-B-100 (High-Purity Standards, USA) samples and a standard MS-3 solution containing all necessary stable metal elements

were used as reference.

First, the surface contamination was removed with a scalpel. Then, samples were cleaned from organic mudding via treatment with a solvent (ethanol) in an ultrasonic bath and subsequent drying. After that, samples were weighed on a Sartorius MSE3.6P-000-DM Cubis Micro Balance (Germany), placed into Sarstedt vials of 50 ml, and dissolved in 3 ml of nitric acid. After complete dissolution of samples, the mass of each solution was topped up to 50 g using a 2% water solution of nitric acid.

Analytical research was performed on equipment of the Shared Knowledge Center “Scientific Research Analytical Center of NRC ‘Kurchatov Institute’ - IREA” (IREA Shared Knowledge Center).

3. Results and discussion

3.1. The archaeozoological study of faunal assemblage

Most animal bones come from kitchen midden. Almost all bones belong to domesticated ungulates. Cattle bones are prevalent (*Bos taurus*), they account for more than 70% of all bone remains. Sheep and goats account for around 25%. The share of horse bones (*Equus caballus*) does not exceed 2%, the share of pig bones (*Sus scrofa domestica*) is 1%. The assemblage also contains some dog bones as chance finds; these bones of domesticated dogs (*Canis familiaris*) that belonged to the settlement occupants were not found in kitchen midden (Table 1).

The slaughter age was estimated for prevalent species, i.e. cattle and sheep/goats (Fig. 7).

The age of the cattle stock was estimated by analyzing 297 mandible specimens and 133 individual teeth. The analysis of the cattle age groups demonstrates that half of the animals were young animals slaughtered at the age of 1.5–2.5 years while the other half of the animals were adult animals slaughtered at the age over 2.5 years. More importantly, 50% of all adult species were slaughtered at the age of 2.5–3 years, which means that the animals were slaughtered when they reached their peak weight. Animals of 3–6 years that form the breeder's stock account for 30% of all adult animals consumed for food. The share of species older than 4–6 years is around 26.0%. According to the zootechnical rules of animal husbandry when animals are kept in enclosures at the settlement, the removal rate of young animals (from 8 months to 2.5 years) from stock should not exceed 40% (Antipina, 2008: 72–73). Otherwise natural reproduction becomes impossible. In our case, the share of this age group is around 50% (Table 1). This may be explained by three factors:

- Animals were brought from other places, possibly, to be exchanged for ore;
- A free range system was used, under this system only part of the herd is consumed for food, the remaining animals graze far away from the settlement;
- The settlement is seasonal and animal bones reflect only seasonal slaughter of animals.

Presence of calves from 1 to 3 months of age and 3 to 8 months of age among the slaughtered animals suggests that the Mikhailo-Ovsyanka I population did not only keep animals but also raised them. Interestingly, the cattle bone assemblage includes a small number of very young animals under 18 months of age (2.7%), which is not characteristic for Srubnaya sites located in the southern Middle Volga region (Roslyakova, 2017). We may conclude from this slaughter age analysis that animal husbandry was oriented to production of meat and milk.

We also analyzed the size of adult species of the cattle to assess heterogeneity of the animal stock at Mikhailo-Ovsyanka I. We assessed the size of the first phalanxes as it is the largest group of intact bones (129 specimens). Around 80% of the phalanxes from Mikhailo-

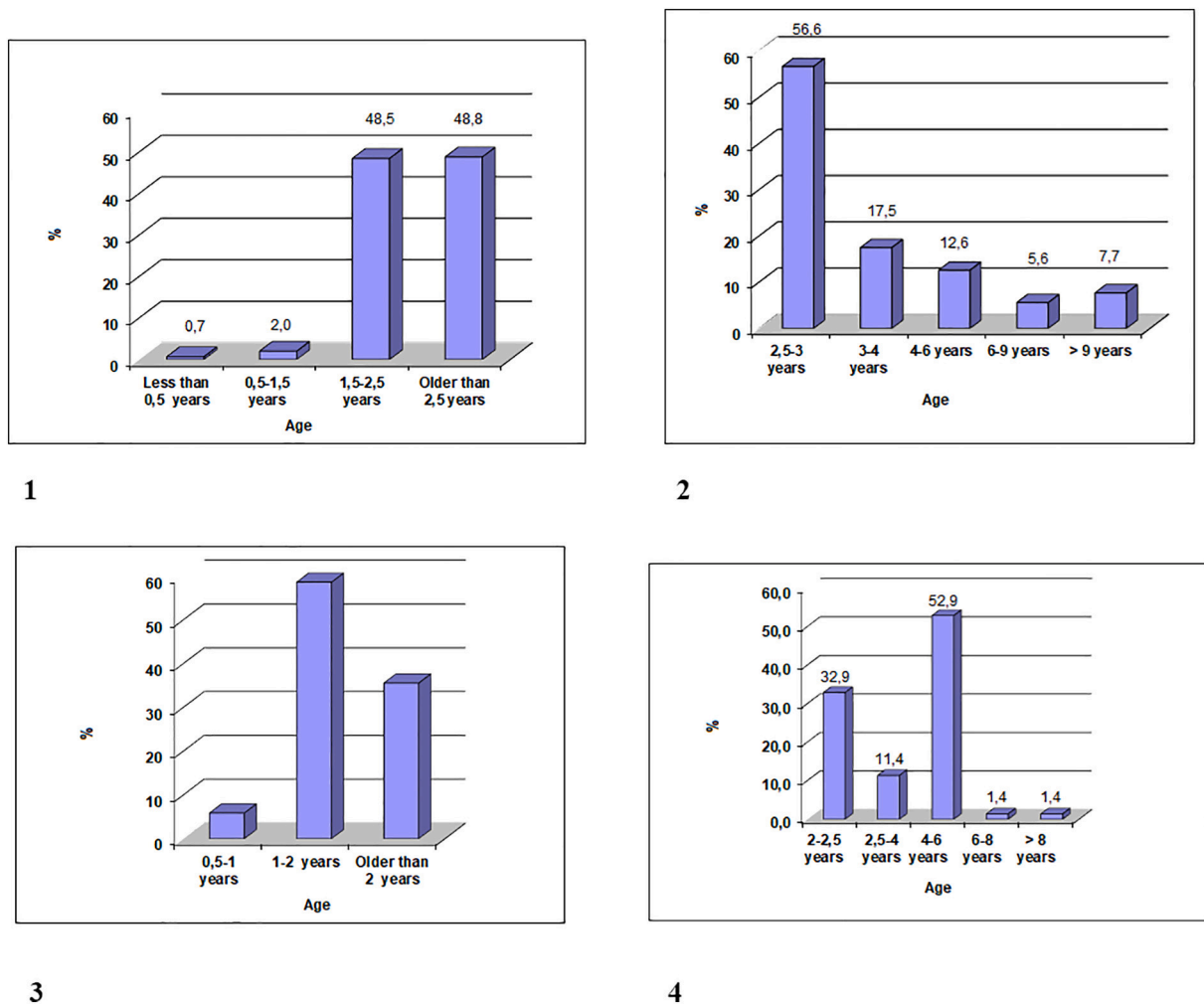


Fig. 7. Mikhailo-Ovtsyanka I: age of slaughtered cattle estimates based on: 1 – dental eruption; 2 – tooth surface loss; age of slaughtered sheep and goat estimates based on: 3 – dental eruption, 4 – tooth surface loss.

Ovtsyanka I are rather small (51–59 mm); it is typical for animals measuring 95 cm at the withers. However, bones of larger animals measuring 120–130 cm at the withers were also found. On the whole, the cattle at Mikhailo-Ovtsyanka I were smaller than the cattle from the Late Bronze Age Srubnaya settlements in the southern Middle Volga region. At the same time, the range of variation in the phalanx length of Mikhailo-Ovtsyanka animals I is similar to that of animals from other Srubnaya sites of the southern Middle Volga region (Fig. 8). It means that the use of this variable does not serve to identify the presence of animals from other settlements at Mikhailo-Ovtsyanka I.

The study of 256 mandibles and 16 individual teeth of sheep and goats demonstrated similar results. Most sheep and goats (64.5%) were consumed for food before animals reaching their peak weight, i.e. when they were still under two years. The slaughter of such a large number of young animals would have destroyed the breeder's stock in case animals had been kept in enclosures. Animals of productive age (from 2 to 6 years) are represented in kitchen midden (around 35%). At the same time one third of all adult animals was slaughtered at the age of 2–2.5 years, while half of adult animals were slaughtered at the age of 4–6 years. The share of old animals is around 3% of adult animals. These data probably imply that that sheep and goats were used at Mikhailo-Ovtsyanka I for meat and production of milk and wool. This conclusion is also evidenced by an implement for sheep shearing made from a rib of a sheep or goat discovered at the settlement. The remains of sheep and goat yielded mandibles of young animals of 1–4 months of age (1 specimen) and 4–12 months of age (6 specimens). Apparently,

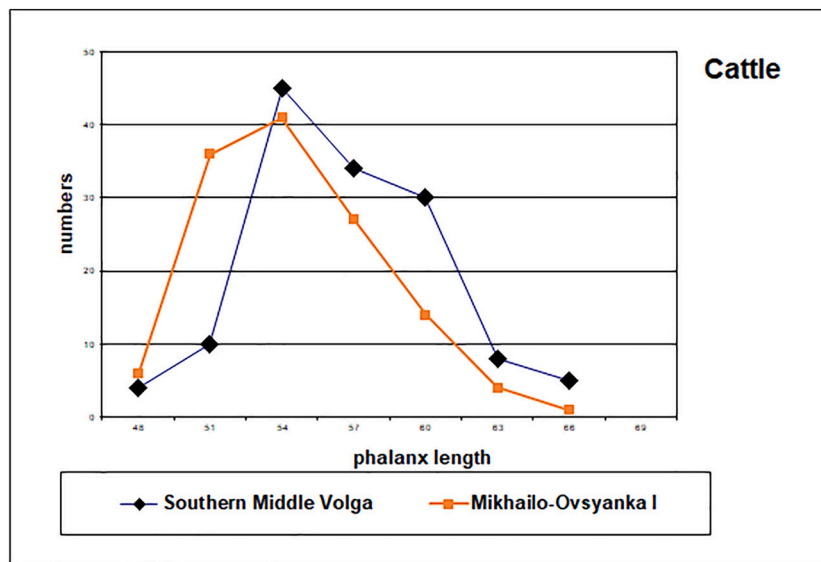
they were born at Mikhailo-Ovtsyanka I or at nearby settlements.

The size of the sheep and goats from Mikhailo-Ovtsyanka I is consistent with the average size of sheep and goats at Bronze Age Srubnaya settlements in the southern Middle Volga region. Measurements were done for 30 specimens from Mikhailo-Ovtsyanka I. The size of the sheep and goats is consistent with the average size of sheep and goats from other Srubnaya settlements located in the southern Middle Volga region (Fig. 8).

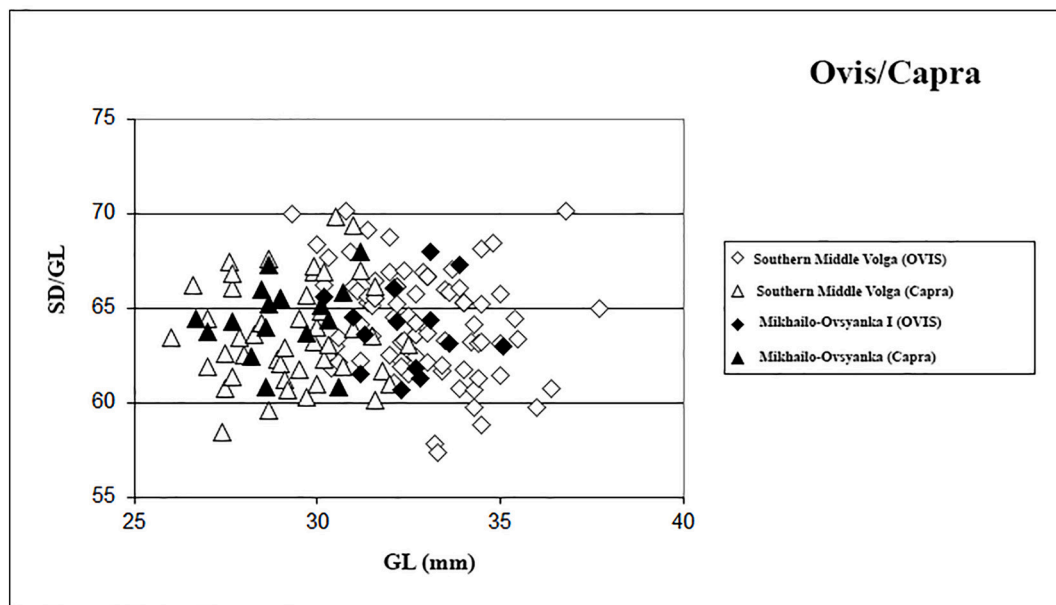
Considering the results of the archaeozoological analyses described, it may be concluded that, most likely, the Mikhailo-Ovtsyanka I population raised and kept domesticated animals at the site. This conclusion is confirmed by bones of newborn sheep, goats and cattle at the site. Domesticated animals were not kept in enclosures at the settlement all year round. Maybe, these animals were from nearby Srubnaya settlements whose occupants were involved in search, extraction of ore and smelting activities. This is confirmed by the presence of a great number of young animals consumed for food at the settlement, which is not a viable husbandry practice that includes keeping animals in enclosures at the settlement. Most likely, domesticated animals grazed at a distance from the settlement while only part of the stock was kept at the settlement or in its vicinity.

3.2. Stable isotope data of the animal bone

The collagen atomic C/N ratio ranges from 3.0 to 3.3 (Table 2) except for one sample with the C/N ratio of 4.3. This sample was



1



2

Fig. 8. Mikhailo-Ovskyanka I: 1 – variational series of the first phalanx length for the Mikhailo-Ovskyanka I cattle and the cattle from other southern Middle Volga Srubnaya settlements; 2 – size and proportions of the sheep and goat astragal bones from Mikhailo-Ovskyanka I and the Srubnaya settlements in the southern Middle Volga region.

excluded from the analyses. All extracts satisfy the criteria defined for collagen yielding reliable stable carbon and nitrogen isotope ratios (DeNiro, 1985).

The isotopic composition of the domesticated animal bones from three constructions at Mikhailo-Ovskyanka I demonstrates that the animals grazed in open C_3 grasslands and pastures with mixed C_3/C_4 plants (Balasse et al., 2014) (Fig. 9).

Data on the isotopic composition of pasture-fed animals obtained from Srubnaya sites dating to the second millennium BCE which were located in the forest-steppe, steppe and arid steppe zones of the southern part of the Russian Plain as well as from the northern Caucasus were used for comparison (Shishlina et al., 2018). The comparative analysis enables us to exclude arid, forest-steppe and foothills areas

from the list of potential pastures (Fig. 9). The pilot data on the isotopic composition of the domesticated animal bones offer a hypothetical model of the local grassland system under which almost all animals grazed within a rather limited area, possibly, within the Irgis river valley and the closest watersheds.

The isotopic data also confirmed the results of the archaeozoological analysis on free range grazing of animals from Mikhailo-Ovskyanka I and suggested the use of grasslands with mixed plants. The local Srubnaya population practiced free range animal husbandry and used an optimal system of pasturing based on the use of different pastures. Most likely, such pastures were located in special geomorphological, orographic and climatic conditions.

Table 2
Stable isotope composition ($\delta^{13}\text{C}$, $\delta^{15}\text{N}$) of Mikhailo-Ovsyanka I animal bones.

Specimen	$\delta^{13}\text{C}$, ‰	$\delta^{15}\text{N}$, ‰	C:N
	VPDB	AIR	
Excavation trench III, construction 1			
Right mandible, cattle	-21.5	5.9	3.0
Right mandible, goat	-19.6	5.7	3.0
Left mandible, sheep	-19.2	7.6	3.0
Right mandible, sheep/goat	-19.3	7.5	3.0
Intermaxilla of the maxilla, horse	-21.8	7.4	3.1
Sheep bone	-20.3	3.9	3.0
Sheep bone	-20.9	6.7	3.0
Sheep bone	-19.9	3.2	3.0
Sheep bone	-19.7	7.5	3.0
Excavation trench III, construction 2			
Sheep bone	-19.6	7.4	3.0
Excavation trench IV, construction 4			
Cattle bone	-20.3	3.4	3.2
Cattle bone	-19.3	7.5	3.3
Sheep bone	-19.7	3.2	3.3
Cattle bone	-20.0	4.3	3.1

3.3. Strontium isotopic composition ($^{87}\text{Sr}/^{86}\text{Sr}$) of animal teeth

The variation in strontium isotopes in the tooth enamel and dentin of domesticated and wild (marmot) animals (Table 3) clearly demonstrates that three animals—two cows and one sheep (excavation trench III, construction 17; excavation trench III, construction 1)—can be referred to the local group of animals while one cow and one sheep from excavation trench III, construction 1, was probably non-local or grazed in distant pastures or flood-meadows with more radiogenic isotopic ratios corresponding to different carbonate dominated areas and river water, respectively (Fig. 10).

The variations of $^{87}\text{Sr}/^{86}\text{Sr}$ ratios for the southern part of Russia, especially, the steppe and mountain zones, lead to complexity in interpretation. A cow with the highest $^{87}\text{Sr}/^{86}\text{Sr}$ ratio could have been brought from the adjacent areas with Triassic-Jurassic deposits containing altered sandstones, clays and conglomerates, possessing high $^{87}\text{Sr}/^{86}\text{Sr}$ ratios (40–50 km north-east of Mikhailo-Ovsyanka I). At the same time, we cannot rule out that this cow grazed on flood-meadow pastures of flood-prone areas of a river/rivers located near Mikhailo-Ovsyanka I. The river waters that passed through the Triassic-Jurassic rocks of the Upland may have inherited such high $^{87}\text{Sr}/^{86}\text{Sr}$ ratios (average value of global river run-off is 0.7119–0.7136). Nevertheless, the mean value of $^{87}\text{Sr}/^{86}\text{Sr} = 0.70802$ in Volga river basin (about 100 km north-east of Mikhailo-Ovsyanka I) is rather low probably due to geology and a large drainage area.

Therefore, the pilot data on strontium isotopes in the tooth enamel demonstrate that the sheep and the cattle, most likely, belonged either to the miners or inhabitants of the neighboring villages involved in the mining production process. The isotope composition and variations in $^{87}\text{Sr}/^{86}\text{Sr}$ demonstrate that non-local cows and sheep were probably brought from afar and were exchanged for valuable copper ingots or items.

3.4. Seasonality of the Mikhailo-Ovsyanka I settlement

New data on the season of animal slaughter along with the data from Pike-Tay and Anthony (2016) demonstrate quite confidently that mining and other works were performed at the site from summer—autumn to early winter (Table 4). We assume that the living and working conditions at this mining site were not appropriate during other seasons of the year. Mixed grass steppe grasslands were located near Mikhailo-Ovsyanka I and at some distance from it; special orographic conditions contributed to a rather high yield of summer and

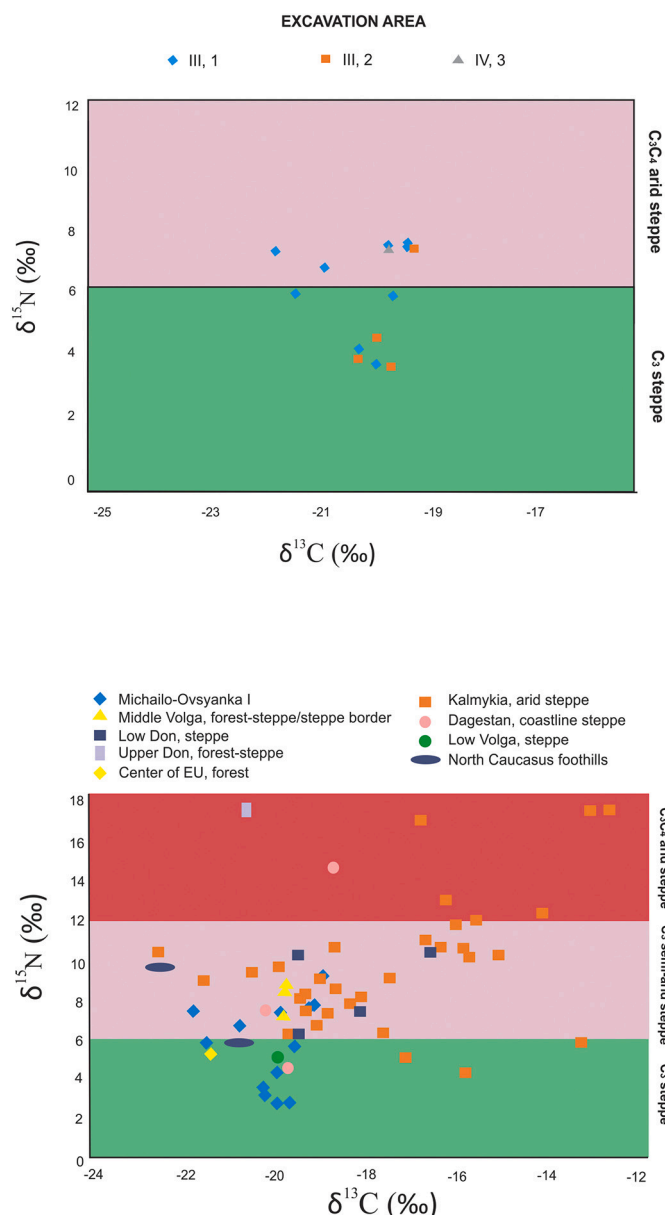


Fig. 9. Stable isotope composition of animal bones ($\delta^{13}\text{C}$ and $\delta^{15}\text{N}$): 1 – Mikhailo-Ovsyanka I, 2 – Srubnaya sites from different areas of eastern Europe.

autumn grasslands. Because of the height of the snow cover they could not be used in winter whereas in spring these grasslands were not rich with plants.

Most likely, work and life came to a standstill at Mikhailo-Ovsyanka I when cold weather set in, the entire population moved away with their animals to winter camps. In spring and early summer herds grazed in pastures located in other places; people did not come back to Mikhailo-Ovsyanka I until mid-summer. Rich summer grasslands around the settlement were used for grazing animals; miners resumed ore searching and mining works and stayed at the site until winter. Animals (cattle and sheep) were also brought from other places to be exchanged for ore/metal/goods. The seasonality of works at Mikhailo-Ovsyanka I correlates with the seasonality of works at Kargaly (Chernykh, 2004) and other Srubnaya mining sites of the Ural region in early second millennium BCE (Tkachev, 2017).

The seasonality of works is also confirmed by the archaeozoological analysis.

Table 3Mikhailo-Ovtsyanka I: variations in the strontium isotopic composition ($^{87}\text{Sr}/^{86}\text{Sr}$) in the samples of the enamel and dentin of animal teeth.

Item	Specimen	Sr, ppm	$^{87}\text{Sr}/^{86}\text{Sr}$	2σ, % (SRM 987, n = 249)
Excavation trench II, construction 17				
1	Cattle, mandible 1, M ₂ , dentin	579	0.708951	0.003
1a	Cattle, mandible 1, M ₂ , enamel	558	0.708868	0.003
2	Sheep/goats, mandible 1, M ₃ , dentin	590	0.709219	0.003
2a	Sheep/goats, mandible 1, M ₃ , enamel	250	0.708733	0.003
Excavation trench III, construction 1				
3	Cattle, mandible 1, tooth, enamel	–	0.709768	0.003
4	Sheep/goats, mandible 4, tooth, enamel	–	0.709253	0.003
Baseline, Excavation trench III, construction 2, AIII-5				
5	Marmot mandible, tooth, dentin	297	0.709048	0.003
5a	Marmot mandible, tooth, enamel	237	0.708778	0.003

3.5. Mass spectrometry analysis

The results of ICP-MS and ICP-AES analysis are summarized in Table 5. This analysis clearly shows that the metal of the artifacts is practically one-component alloy. Impurities are present as trace elements and are less than 0.4 w%. Therefore, production activities of the site occupants included not only search and extraction of ore but also its smelting and even manufacturing of copper items for personal use or exchange.

3.6. ^{14}C dating

The ^{14}C dating of the animal bones retrieved from two constructions found in excavation trench III (Table 6, Fig. 11) suggests that searching for ore at the mining site began approximately in 1800 calBC, i.e. one hundred years earlier than active development of ore reserves in the Kargaly field in the Cis-Urals. The mining activity at Mikhailo-

Ovtsyanka I continued for roughly 100–150 years. At first, searching for ore was successful, ore was extracted, pure copper was produced, items were cast right at the site and ore, metal and produced goods were exchanged for animals (cattle). However, many mines did not contain ore, they were abandoned and filled up with refuse and waste, and searching for new ore outcrop continued.

It appears that the mining activity at Mikhailo-Ovtsyanka I continued for a short time as the ore was of low grade and its extraction and production of metal were not economically viable. This conclusion is evidenced not only by the ^{14}C data but also by the fact that the settlement has only one occupation layer. Starting from 1700 calBC, the Kargaly mining center which was the largest in Eurasia began to be exploited in the Ural region; miners of Gornyy, a huge permanent settlement, produced ore and exchanged it for animals, predominantly, cattle. According to researchers, the Kargaly miners supplied up to 200,000 tons of metal to the areas outside the mining center (Chernykh, 2004). Labor-consuming and not very successful mining works at

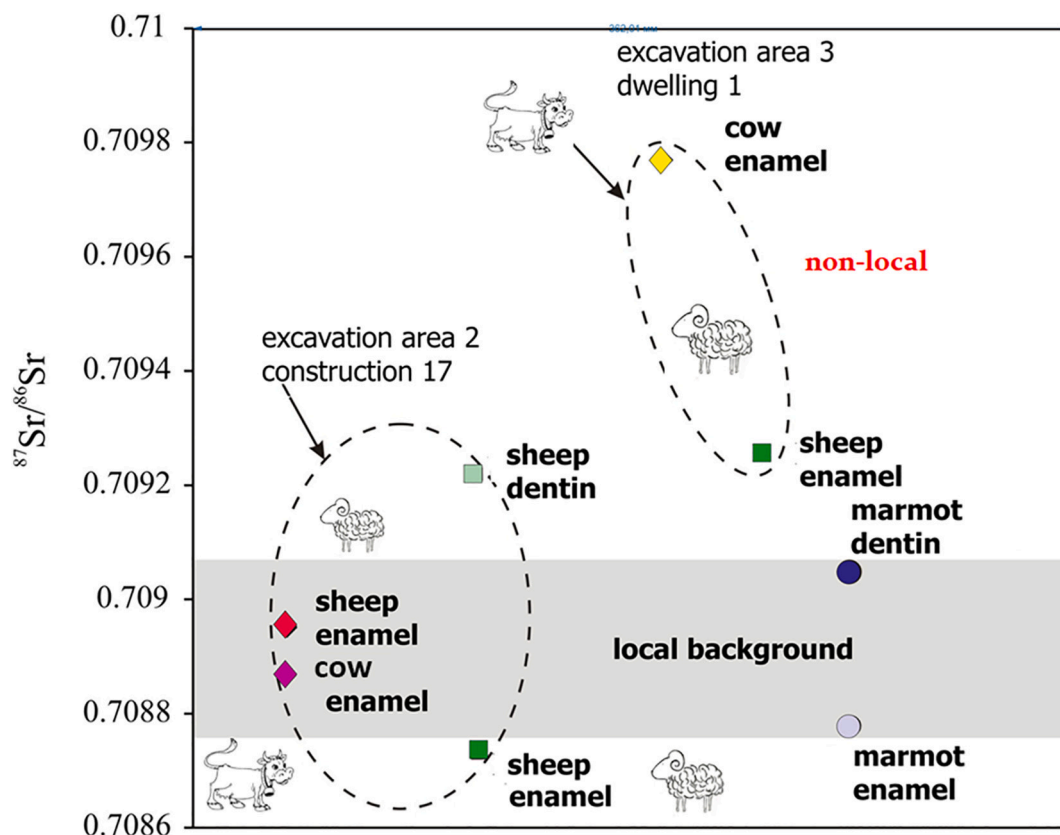


Fig. 10. Mikhailo-Ovtsyanka I: variations in the strontium isotopic composition ($^{87}\text{Sr}/^{86}\text{Sr}$) in the samples of the enamel and dentin of the animal teeth.

Table 4

Mikhailo-Ovsyanka I: animal slaughter season.

Specimen	Age	Slaughter season
Excavation trench II, construction 17		
Cattle, fourth deciduous tooth from the mandible (D ₄)	2.5 years	Late autumn
Cattle, first molar tooth from the mandible (M ₁)	2+ years	Summer
Sheep/goats, second molar tooth (M ₂)	2.5–3 years	Autumn–winter
Excavation trench IV, construction 4		
Cattle, first/s molar tooth from maxilla (M ₁₋₂)	2–3+ years	Late summer–autumn
Cattle, first/s molar tooth from maxilla (M ₁₋₂)	3.5 years	Late autumn
Sheep and goats, first or second molar tooth from maxilla (M ₁₋₂)	3.5 years	Late autumn
Pike-Tay and Anthony (2016)		
Cattle	Subadult, 2.5–5	Late autumn/early winter
Sheep/goat	–	Late autumn/early winter

Table 5

Mikhailo-Ovsyanka I: mass-spectrometry data.

Sample	Cu	Zn	Sn	Pb	Al	Fe	Ni	As	Se	Ag	Sb	Na	Mg	Si	K	V	Co	Rh
C, mass %																		
Pendant	99.53	0.017	0.002	0.016	0.007	0.167	0.028	0.079	0.001	0.035	0.001	0.003	0.005	0.004	0.001	0.001	0.004	0.001
awl	99.648	0.006	0.002	0.041	0.002	0.079	0.007	0.026	0.002	0.084	0	0	0	0	0	0	0.001	0.001
ingot	99.681	0.005	0.002	0.082	0.001	0.062	0.015	0.025	0.002	0.023	0.001	0	0	0	0	0	0.001	0.001

Mikhailo-Ovsyanka I were stopped and the mining site was abandoned.

Maybe, people returned to Mikhailo-Ovsyanka I later as evidenced by the ¹⁴C data for a cow bone from construction 1 in excavation trench III (1600–1500 BCE) and one more, even later date for charcoal (Anthony et al., 2016) which, apparently, dates to the period when the miners' settlement was completely abandoned.

4. Conclusion

Our comprehensive analyses clearly demonstrate that economy of the Srubnaya population inhabiting the Middle Volga region in the Late Bronze Age was based on animal husbandry and copper-based metallurgy (Peterson et al., 2016: 322). This subsistence model was basic for the inhabitants of the steppe and forest-steppe areas of the Volga-Urals regions, for example, the Kozhoumberdinsky variant of the Alakul culture in the Ural-Mugodzhary Region (Tkachev, 2017). The study of

Table 6¹⁴C data obtained for the animal bones from Mikhailo-Ovsyanka I, excavation trench III.

Lab number	Specimen	¹⁴ C age(BP)	Calibrated range 1σ (BC) [start: end] relative area	δ ¹³ C, ‰	δ ¹⁵ N, ‰
Construction 1 Poz-96,698	Sheep bone	3360 ± 30	68.2% probability 1688 BCE (68.2%) 1622 BCE 95.4% probability 1742 BCE (10.4%) 1710 BCE 1700 BCE (79.6%) 1606 BCE 1584 BCE (5.5%) 1546 BCE	–	–
GrA-69,480	Sheep bone	3450 ± 35	68.2% probability 1872 BCE (15.7%) 1844 BCE 1813 BCE (5.6%) 1801 BCE 1778 BCE (30.1%) 1732 BCE 1720 BCE (16.8%) 1693 BCE 95.4% probability 1882 BCE (95.4%) 1683 BCE	–19.7	7.5
IGAN _{AMS} 5646/ UGAMS-30191	Cattle bone	3230 ± 25	68.2% probability 1526 BCE (38.1%) 1492 BCE 1481 BCE (30.1%) 1454 BCE 95.4% probability 1606 BCE (5.7%) 1582 BCE 1558 BCE (0.7%) 1554 BCE 1546 BCE (89.0%) 1433 BCE	–	–
Construction 2 GrM-10195	Sheep bone	3455 ± 15	68.2% probability 1865 BCE (14.5%) 1849 BCE 1773 BCE (42.1%) 1740 BCE 1711 BCE (11.6%) 1700 BCE 95.4% probability 1876 BCE (22.5%) 1840 BCE 1822 BCE (7.8%) 1796 BCE 1782 BCE (47.8%) 1732 BCE 1720 BCE (17.3%) 1692 BCE	–19.6	7.4

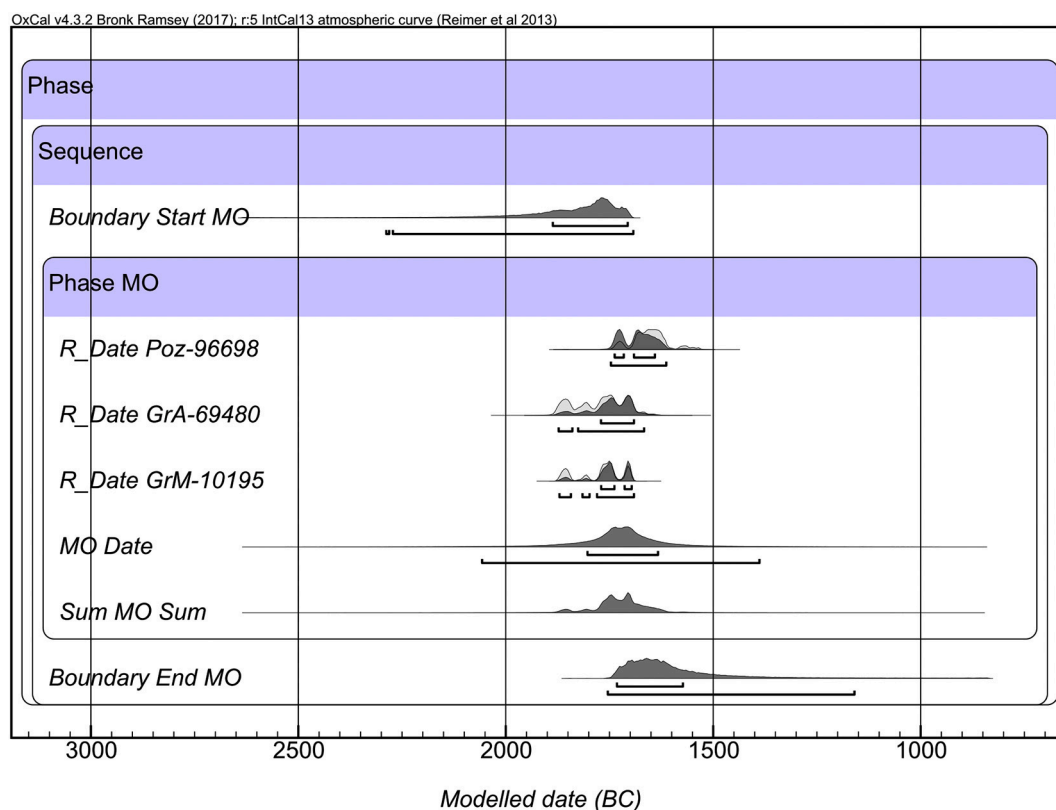


Fig. 11. ^{14}C data from Mikhailo-Ovsyanka I: estimated total probability, OxCal 4.3 (Bronk Ramsey, 2009).

the archaeozoological assemblages from the Srubnaya Mikhailo-Ovsyanka I settlement located in the south of the Samara region confirm these findings. Main activities of the local population centered on mining; free range animal husbandry was a secondary occupation; free range animal husbandry was a secondary activity.

Under the Samara Valley project D. Antony compared the data obtained for the Krasnosamarskoye site located in the Samara River valley with the pilot data from Mikhailo-Ovsyanka I. In his view, Mikhailo-Ovsyanka I was provisioned with labor and food from surrounding Srubnaya communities like Krasnosamarskoye (Anthony et al., 2016a: 45).

The subsistence system of the Srubnaya local population inhabiting Mikhailo-Ovsyanka I that was developed included the following production and economic processes: The local Srubnaya population searched ore, mined oxide minerals, smelted metal, and cast items on a seasonal basis. Mining was their primary occupation.

- (1) Metal-animal exchange system began to evolve in the Middle Volga region in 1800 calBC. Ore/metal/goods were exchanged for animals.
- (2) The animal stock included cattle, sheep, goats and horses. Free range animal husbandry with seasonal grasslands was used on a rotational basis. The animals lived, were slaughtered and consumed at the site or in nearby areas seasonally. Pasturing was their secondary occupation.

Most likely, the grazing areas around the mining site were not used in winter and spring, nobody lived at the settlement, the animals were moved to other areas which is confirmed by the isotopic composition of pasture-fed animals. The season of various animal slaughters reveals that the mining settlement was occupied and exploited in summer and autumn, though further to the north there were permanent Srubnaya settlements such as Krasnosamarskoye where people lived all year round (Pike-Tay and Anthony, 2016).

Inhabitants of other Srubnaya settlements, most likely, located nearby were probably involved in seasonal searching for ore, metalworking, trade and exchange, some domestic activities (cooking, small-scale crafts, keeping animals, etc.). This conclusion is based on the analysis of variation in the strontium isotope composition of domesticated animals which demonstrates that most animals were local.

The staple food of the local population is meat of domesticated animals, many animals were slaughtered for food before reaching the maximum weight. Presence of calves from 1 to 3 months of age and 3 to 8 months of age and the sheep from 1 to 3 months of age and from 4 to 12 months of age among the slaughtered animals suggests that these animals were probably born in winter–spring, summer and autumn. Because of specific orographic and climatic conditions of the steppe area where the Mikhailo-Ovsyanka I miner's settlement is located such as a high level of humidity during summer months, lands located near watershed plateaus and steppe river valleys could be used for pastures. The analysis of the size of the adult cattle, goat and sheep species indicates that Mikhailo-Ovsyanka cattle were slightly smaller in size compared to the Bronze Age settlements in the south of the Middle Volga region. The range of the cattle bone variability is typical for one population. The local groups primarily exploited the resources in the Iriz river basin.

The presence of non-local cattle suggests that the metal-animal exchange system began to evolve during development of such small resource metallurgical centers as Mikhailo-Ovsyanka I in the Middle Volga region roughly in 1800 calBC. However, the mineral resources were not rich and, most likely, the miners were forced to begin searching for other deposits.

A special ore/metal–animals exchange system was developed at Gorny, which was a large mining site of the Srubnaya population in the Urals where people lived all year round, extracting ore and exchanging it for cattle throughout three hundred years (Chernykh, 2007).

The development of copper mining sites located in other regions such as Kazakhstan with severe natural conditions was seasonal, copper

concentrate (beneficated ore) remained the main product for exchange (Tkachuk, 2017: 217; 223).

Author statement

The work described in this manuscript “Animals, metal and isotopes: Mikhailo-Ovsyanka I, the Late Bronze Age mining site of the steppe Volga region is entirely original and has not been submitted for publication elsewhere.

Declaration of Competing Interest

The manuscript “Animals, metal and isotopes: Mikhailo-Ovsyanka I, the Late Bronze Age mining site of the steppe Volga region” is based on the investigation of archaeological animal bone collection obtained from the Mikhailo-Ovsyanka site of the Late Bronze Age. The project was supported by the Russian Fund of Basic Research, grant # grant OFI-m 17-18-01399 and under the support of State program №33.1907.2017. All results were discussed with the team members. There is no conflict of interest.

The work described in this manuscript is entirely original and has not been submitted for publication elsewhere.

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References

- Agapov, S.A., Vasiliev, I.B., 1976. New Srubnaya settlements in the Kuibyshev Trans-Volga region. In: Vasiliev, I.B. (Ed.), *Overviews of History and Culture in the Volga Region*, Issue. 2. Interstitute Izdatelstvo, Kuibyshev, pp. 97–112.
- Ambrose, S.H., DeNiro, M.J., 1986. The isotopic ecology of East Africa mammals. *Oecologia* 69, 395–406.
- Anthony, D.W., Brown, D.R.E., Khokhlov, A.A., Kuznetsov, P.F., Mochalov, O.D. (Eds.), 2016. *A Bronze Age Landscape in the Russian Steppes. The Samara Valley Project*. UCLA Cotsen Institute of Archaeology Press, LA (513 pp.).
- Anthony, D.W., Brown, D.R., Kuznetsov, P.F., 2016b. Archaeological field operations in the Lower Samara Valley, 1995–2001, with observations on Srubnaya Pastoralism. In: Anthony, D.W., Brown, D.R.E., Khokhlov, A.A., Kuznetsov, P.F., Mochalov, O.D. (Eds.), 2016. *A Bronze Age Landscape in the Russian Steppes. The Samara Valley Project*. UCLA Cotsen Institute of Archaeology Press, LA, pp. 37–60.
- Antipina, E.E., 2004. Archaeozoological materials. In: Chernikh, E.N. (Ed.), *Kargaly, Volume III. The Gorny Site: Archaeological Materials, Mining and Metallurgical Production Technologies, Archaeobiological Studies. Collected Papers. IA RAS*, Moscow, pp. 182–239.
- Antipina, E.E., 2008. The composition of the domesticated animal herd: logical approximations. In: *OPUS: Interdisciplinary Studies in Archaeology*. 6. Institute of Archaeology, Moscow, pp. 67–85.
- Balase, M., Tornero, C., Brehard, S., Ughetto-Monfrin, J., Vionea, V., Bălăşescu, A., 2014. Cattle and sheep herding at Cheia, Romania, at turn of the fifth millennium cal BC. *Proceedings of British Academy* 198, 115–122.
- Bentley, R.A., Price, T.D., Stephan, E., 2004. Determining the local $^{87}\text{Sr}/^{86}\text{Sr}$ range for archaeological skeletons: a case study from Neolithic Europe. *J. Archaeol. Sci.* 31, 365–375.
- Boessneck, J., Müller, H., Teichert, M., 1964. Osteologische Unterscheidungsmerkmale zwischen Schaf (*Ovis aries* Linne) und Ziege (*Capra hircus* Linne). *M ünchen: Kühn-Archiv. Band 78, Heft 1–2* (129 pp.).
- Bogaard, A., Heaton, T.H.E., Poulton, P., Merbach, I., 2007. The impact of manuring on nitrogen isotope ratios in cereals: archaeological implications for reconstruction of diet and crop management practices. *J. Archaeol. Sci.* 34, 335–343.
- Bronk Ramsey, C., 2009. Dealing with outliers and offsets in radiocarbon dating. *Radiocarbon* 51 (3), 1023–1045.
- Chernykh, E.N., 2007. Kargaly: phenomenon and paradoxes of development. Kargaly in the system of Metallurgical Provinces. Hidden (sacral) life of archaic miners and metallurgists. In: *Languages of Slavonic Culture*, Moscow, 199 pp.
- Chernykh, E.N., Lebedeva, E.Yu., Zhurbin, I.V., Lopez-Saets, Kh.A., Lopez-Garci, A.P., Martinez-Navaret, M.I.N., 2002b. Kargaly. Volume II. Gorny as a settlement of the Late Bronze Age: topography, lithology, stratigraphy: production and household and sacral constructions. Relative and absolute chronology. In: *Languages of Slavonic Culture*, Moscow, 182 pp.
- Chernykh, E.N., Lebedeva, E.Yu., Kuzminykh, S.V., Lunkov, V.Yu., Gorozhanin, V.M., Gorozhanina, E.N., Ovchinnikov, V.V., Puchkov, V.N., 2002a. Kargaly. In: *Volume I. Geological and Geographic Characteristics: History of Discoveries, Operation and Research. Archaeological Sites. Languages of Slavonic Culture*, Moscow, 190 pp.
- DeNiro, M.J., 1985. Post-mortem preservation and alteration of in vivo bone collagen isotope ratios in relation to paleodietary reconstructions. *Nature* 317, 806–809.
- von den Driesch, A., 1976. *A Guide to the Measurement of Animal Bones from Archaeological Sites*. Harvard University, Harvard (Peabody Museum, Bulletin 1. 71 pp.).
- Gerling, C., 2015. *Prehistoric Mobility and Diet in the West Eurasian Steppes. 3500 to 300 BC*. De Gruyter, Berlin/Boston, pp. 402.
- Gorashchuk, I.V., Kolev, Yu.I., 2004. Stone and bone tools from the Mikhailo-Ovsyanka mining site of the Bronze Age in the Samara region. In: Vyborno, A.A. (Ed.), *Issues of Archaeology of the Urals and the Volga Region. Issue 2. Samara State Pedagogical Institute, Samara*, pp. 89–102.
- Grant, A., 1982. The use of tooth wear as a guide to the age of domestic ungulates. In: Wilson, B., Grigson, C., Payne, S. (Eds.), *Ageing and Sexing Animal Bones from Archaeological Sites*. 109. BAR (British Series), Oxford, pp. 91–108.
- Greenfield, J., Moore, N.C., Stepan, K., 2015. Estimating the age- and season-of-death for wild Equids: a comparison of techniques utilising a sample from the late neolithic site of Bad Buchau-Dullenried, Germany. *Open Quaternary* 1 (3), 1–28.
- Gromova, V.I., 1953. Osteological differences between goat and ram species. *Proceedings of the Quaternary Commission* 10 (1), 124.
- Grue, H.E., Jensen, B., 1979. Review of the formation of incremental lines in tooth cementum of terrestrial mammals. *Danish Review of Game Biol* 11 (3), 1–48.
- Iacumin, P., Nikolayev, V., Ramigni, M., 2000. Paleoenvironmental reconstruction by means of isotopic studies of the Late Pleistocene megafauna in Northern Eurasia. *Journal of Geocryology* 2, 153–170.
- Klevezal, G.A., 1988. *Recording Structures of Mammals in Zoological Studies*. Nauka, Moscow 142 pp.
- Klevezal, G.A., Kleinenberg, S.E., 1967. *Determination of the Mammal Age Based on Tooth and Bone Layers*. Nauka, Moscow 144 pp.
- Kuznetsov, P.F., Mochalov, O.D., 2016. The Samara Valley in the Bronze Age: a review of archaeological discoveries. In: Anthony, D.W., Brown, D.R.E., Khokhlov, A.A., Kuznetsov, P.F., Mochalov, O.D. (Eds.), *A Bronze Age Landscape in the Russian Steppes. The Samara Valley Project*. 2016. UCLA Cotsen Institute of Archaeology Press, LA, pp. 71–90.
- Lebedeva, E.Yu., 2005. Archaeobotany and studies of crop growing in Eastern Europe during the bronze age. In: Dobrovolskaya, M.V. (Ed.), *OPUS: Interdisciplinary Studies in Archaeology*. 4. pp. 50–68.
- Longin, R., 1971. New method of collagen extraction for radiocarbon dating. *Nature* 230, 241–242.
- Matveeva, G.I., Kolev, Yu.I., Korolev, A.I., 2004. Metallurgical Bronze Age site near vil. Mikhailo-Ovsyanka on the southern part of the Samara oblast (first results and issues). In: Vyborno, A.A. (Ed.), *Issues of Archaeology of the Urals and the Volga Region. Issue 2. Samara State Pedagogical Institute, Samara*, pp. 69–88.
- Mook, W.G., Streuman, H.J., 1983. Physical and chemical aspects of radiocarbon dating. In: *Proceedings of the First Groningen Symposium on C14 and Archaeology*. Part 8, pp. 31–35.
- Nebritov, N.L., 2003. Brief History of Extraction of Ore and Study of Copper on the Middle Cis-Volga and Western Ural Region. *Kraevedcheskiye zapiski*, XI, pp. 127–139.
- Peterson, D.L., Northover, P., Salter, Ch., Maldonado, B., Anthony, D., 2016. Bronze age metallurgy in the middle Volga. In: Anthony, D.W., Brown, D.R.E., Khokhlov, A.A., Kuznetsov, P.F., Mochalov, O.D. (Eds.), 2016. *A Bronze Age Landscape in the Russian Steppes. The Samara Valley Project*. UCLA Cotsen Institute of Archaeology Press, LA, pp. 291–332.
- Pike-Tay, A., 1991. Red Deer Hunting in the Upper Paleolithis of Southwest France: A Study in Seasonality, *BAR International Series S569. Tempus Reparatum*, Oxford, pp. 183.
- Pike-Tay, A., Anthony, D., 2016. Dog days of winter: seasonal activities in a Srubnaya landscape. In: Anthony, D.W., Brown, D.R.E., Khokhlov, A.A., Kuznetsov, P.F., Mochalov, O.D. (Eds.), 2016. *A Bronze Age Landscape in the Russian Steppes. The Samara Valley Project*. UCLA Cotsen Institute of Archaeology Press, LA, pp. 373–384.
- Popova, L.M., 2016. Floral data Analyses: report on the Pollen and Microbotanical remains from the Krasnosamarskoye settlement. In: Anthony, D.W., Brown, D.R.E., Khokhlov, A.A., Kuznetsov, P.F., Mochalov, O.D. (Eds.), 2016. *A Bronze Age Landscape in the Russian Steppes. The Samara Valley Project*. 2016. UCLA Cotsen Institute of Archaeology Press, LA, pp. 333–350.
- Reimer, P.J., Bard, E., Bayliss, A.J., Beck, J.W., Blackwell, P.G., Bronk Ramsey, Ch., Caitlin, E., Buck, C.E., Cheng, C.H., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, Th.P., Haffidason, H., Hajdas, I., Hatté, Ch., Heaton, T.J., Hoffmann, D.L., Hogg, Alan G., Hughen, Konrad A., Kaiser, K. Felix, Kromer, Bernd, Manning, Sturt W., Niu, Mu, Reimer, Ron W., Richards, D.A., Scott, E.M., Southon, J.R., Staff, R.A., Turney, Ch.S.M., van der Plicht, J., 2013. *IntCal13 and Marine13 radiocarbon age calibration curves 0–50,000 years cal BP*. *Radiocarbon* 55 (4), 1869–1887.
- Roslyakova, N.V., 2017. Archaeozoological materials from excavations at the Krotovskiy I settlement. In: Turetsky, M.A. (Ed.), *Issues of Archaeology in the Volga Region*. 6. pp. 474–491.
- Ruhl, L., Herbig, C., Stobbe, A., 2014. Archaeobotanical analysis of plant use at Kamenny Ambar, a Bronze Age fortified settlement of the Sintashta culture in the southern Trans-Urals steppe, Russia. *Veget Hist Archaeobot* 1–14.
- Schwarcz, H.P., Dupras, T.L., Fairgrieve, S.I., 1999. $\delta^{15}\text{N}$ enrichment in the Sahara: in search of a global relationship. *J. Archaeol. Sci.* 26, 629–636.
- Shishlina, N.I., Larionova, Yu.O., 2013. Variations in the isotopic composition of strontium in the samples of contemporary snails from the Russia South: first results. In: Blinks, A.B. (Ed.), *Materials of Historical and Cultural Heritage Studies of the North Caucasus*. Issue XI. Archaeology, Studies of Local Lore, Museum Management Studies, Nasledie, Stavropol, pp. 159–168.
- Shishlina, N.I., Larionova, Yu.O., Idrisov, I.A., Azarov, E.S., 2016. Variations in $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in contemporary snail samples obtained from the Eastern Caucasus. *Arid*

- Ecosystem. 6 (2), 100–106.
- Shishlina, N., Sevastyanov, V., Kuznetsova, O., 2018. Seasonal practices of prehistoric pastoralists from the south of the Russian plain based on the isotope data of modern and archaeological animal bones and plants. *J. Archaeol. Sci. Rep.* 21, 1247–1258.
- Sidelnikov, A.P., 1901. Shape of Surface and Structure of Crust within the Kirgiz Region. Son-Petersburg. pp. 1–250.
- Silver, I., 1969. The Ageing of Domestic Animals, *Science in Archaeology*. pp. 293–302.
- Tkachev, V.V., 2009. Mining and metallurgical centers in the system of archaeometallurgical taxonomy. *Bulletin of Chelyabinsk State University. History* 38 (179), 5–7.
- Tkachev, V.V., 2012. Specific features of the Late Bronze settlements in the Urals-Mugodzhary region (based on interdisciplinary studies). *Urals Archaeological Bulletin* 4 (35), 24–31.
- Tkachev, V.V., 2017. Cultural landscape formation within the Ural-Mugodzhary Region in the Late Bronze Age: development of copper resources and a strategy of adaptation to the mountain-steppe ecosystem. *Stratum Plus* 2, 205–230.
- Trifonov, V.A., Zaitseva, G.I., van der Plicht, J., Burova, N.D., Bogomolov, E.S., Sementsov, A.A., Lokhova, O.V., 2012. The Dolmen Kolikho, Western Caucasus: isotopic investigation of funeral practice and human mobility. *Radiocarbon*. 54 (3–4), 761–769.
- Usquiano, P., 2002. Determination of charcoal remains from Gorny. In: Chernykh, E.N., Lebedeva, E.Yu., Zhurbin, I.V., Lopez-Saets, Kh.A., Lopez-Garcia, P., Martinez-Novelette, M.I.N. (Eds.), *Kargaly. Volume II. Gorny as a Settlement of the Late Bronze Age: Topography, Lithology, Stratigraphy: Production and Household and Sacral Constructions. Relative and Absolute Chronology. Languages of Slavonic Culture*, Moscow. 2002. pp. 166–169.
- Zaitsev, G.N., 1991. *Mathematical Analysis of Biological Data*. Nauka, Moscow 184 pp.